



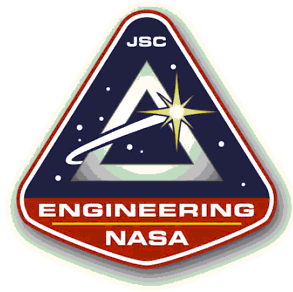
Avionic Systems Division
NASA Johnson Space Center, Houston, Texas

NASA-JSC Wireless Sensor Network Activities Update

Raymond Wagner
Richard Barton

CCDSS Wireless Working Group Face-to-Face
Darmstadt, Germany

April 16, 2012



Agenda

- **Update on ZigBee Pro, ISA100.11a co-existence studies**
- **Update on JSC Modular Wireless Instrumentation (“SSIART-NASA”)**
- **Update on JSC High-Speed Wireless Instrumentation Needs**

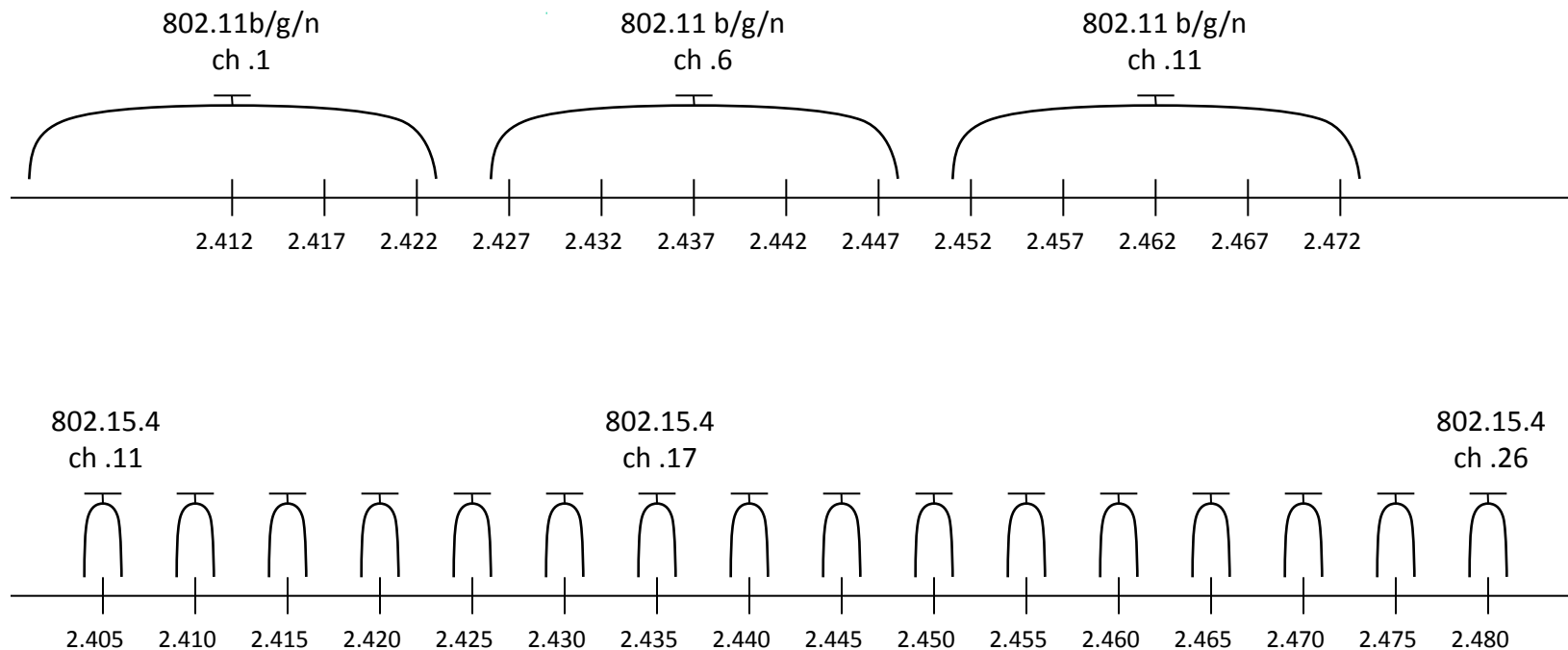


Avionic Systems Division
NASA Johnson Space Center, Houston, Texas

Update on ZigBee Pro, ISA100.11a Co-Existence Studies



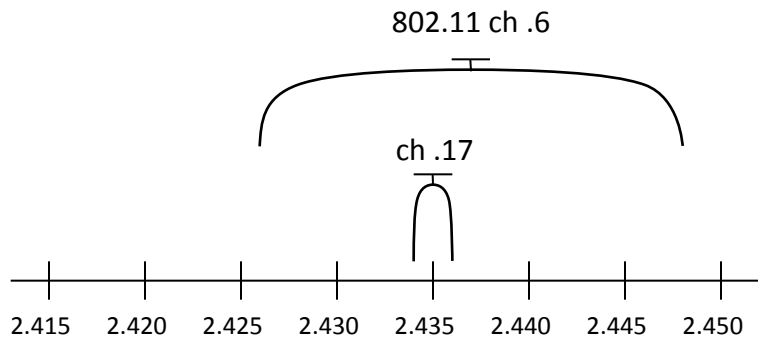
802.15.4, 802.11 Co-existence



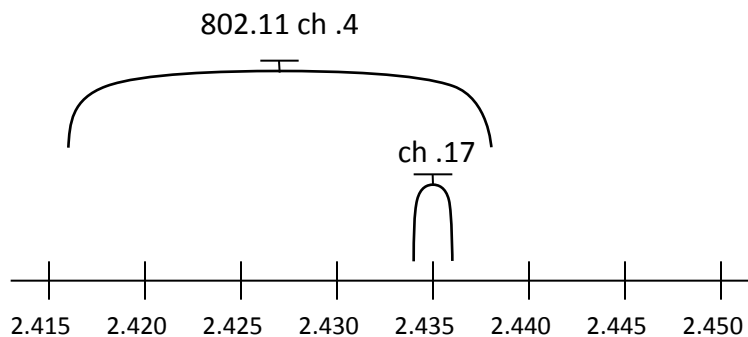


ZigBee, 802.11 Coexistence Investigated

- **Two representative interference patterns:**
 - Wi-Fi ch. 6 interferes with ZigBee ch. 17 near its center frequency
 - Wi-Fi ch. 4 interferes with ZigBee ch. 17 in its sideband



direct



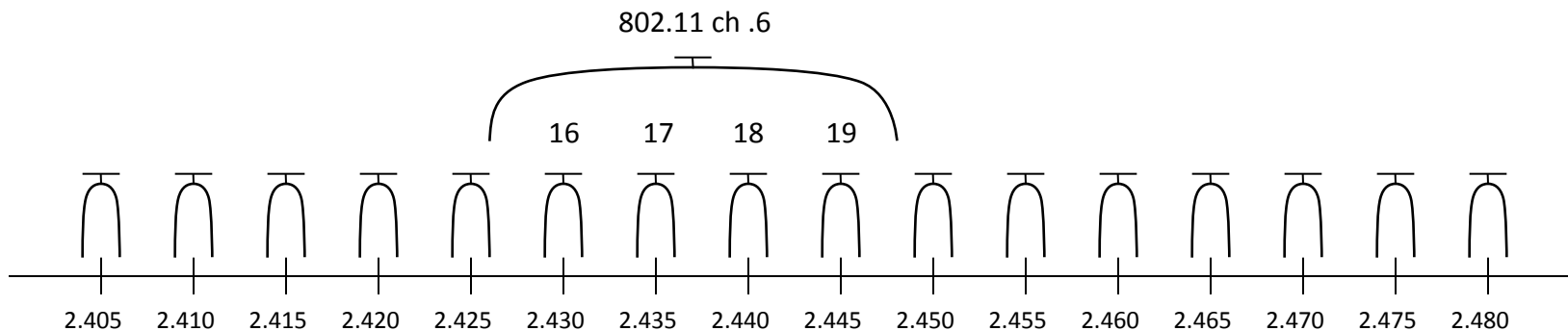
sideband



ISA100, 802.11 Coexistence Investigated

- **One representative interference pattern:**

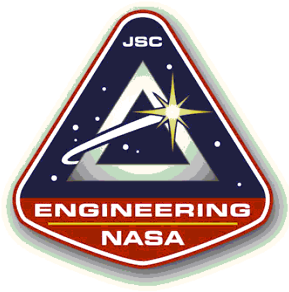
–Wi-Fi ch. 6 interferes with ISA100.11a ch. 17/18 near its center frequency, ch. 16/19 in its sideband





ZigBee, ISA100 Performance Evaluation Methodology

- **Primarily concerned with performance under RF interference conditions:**
 - measure message delivery rate (related to goodput)
 - configure 5 nodes in star topology (primarily tests MACs)
- **IEEE 802.11g router used as interference source:**
 - traffic generated between laptop (wireless to router) and workstation (wired to router) using Iperf
 - flows considered: 0 Mbps, 5 Mbps, 10 Mbps, 20 Mbps
 - also considered maximum single-flow (~ 30 Mbps)
- **Maximum-length packets sent using each protocol at several periodicities:**
 - Packet lengths: 76B
 - Packet periodicities: 1 s/packet, 5 s/packet, 10 s/packet
 - Experiment duration: 1 hour
 - Averaged over 3 trials
 - ~ +3 dBm output power selected for both WSN platforms



ZigBee, ISA100 Performance Evaluation Hardware

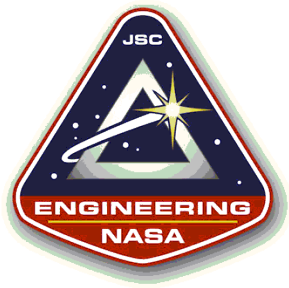
- **JSC WSN node (ISA100.11a):**
 - Nivis VN210 radio, TI MSP430-F5438 microcontroller
- **TI MSP430 Experimenters Board (ZigBee Pro):**
 - TI CC2530 radio (ZigBee Pro stack), TI MSP430-F5438 microcontroller
 - looks identical to custom ZigBee JSC node from application code point of view
 - low-cost stand-in for custom hardware



ZigBee Pro



ISA100.11a



Testbed Environment

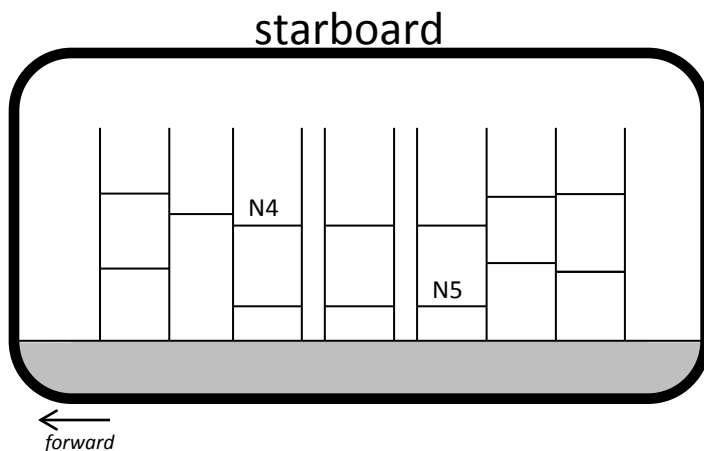
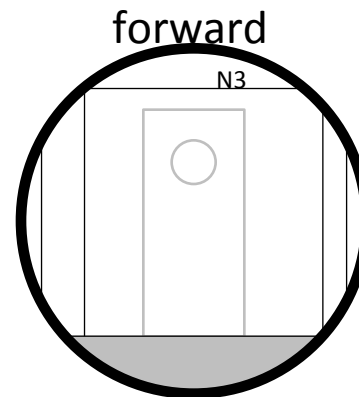
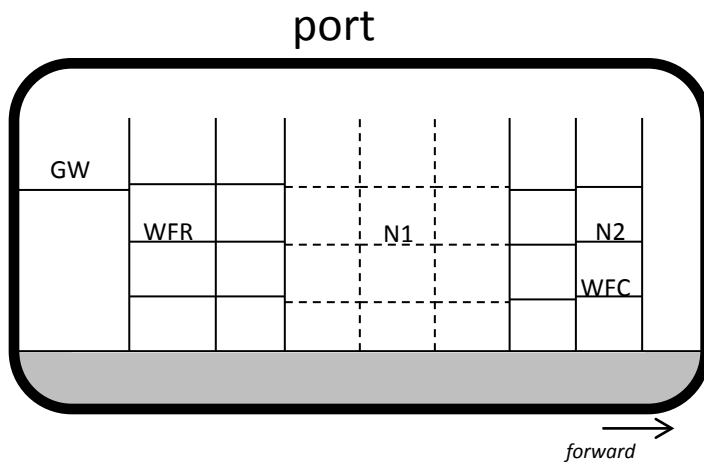
JSC wireless habitat test bed:

- Provides representative, crewed environment for controlled studies
- Good isolation from external RF environment, high level of internal multipath
- Allows interferers to be selectively introduced





Test Hardware Layout

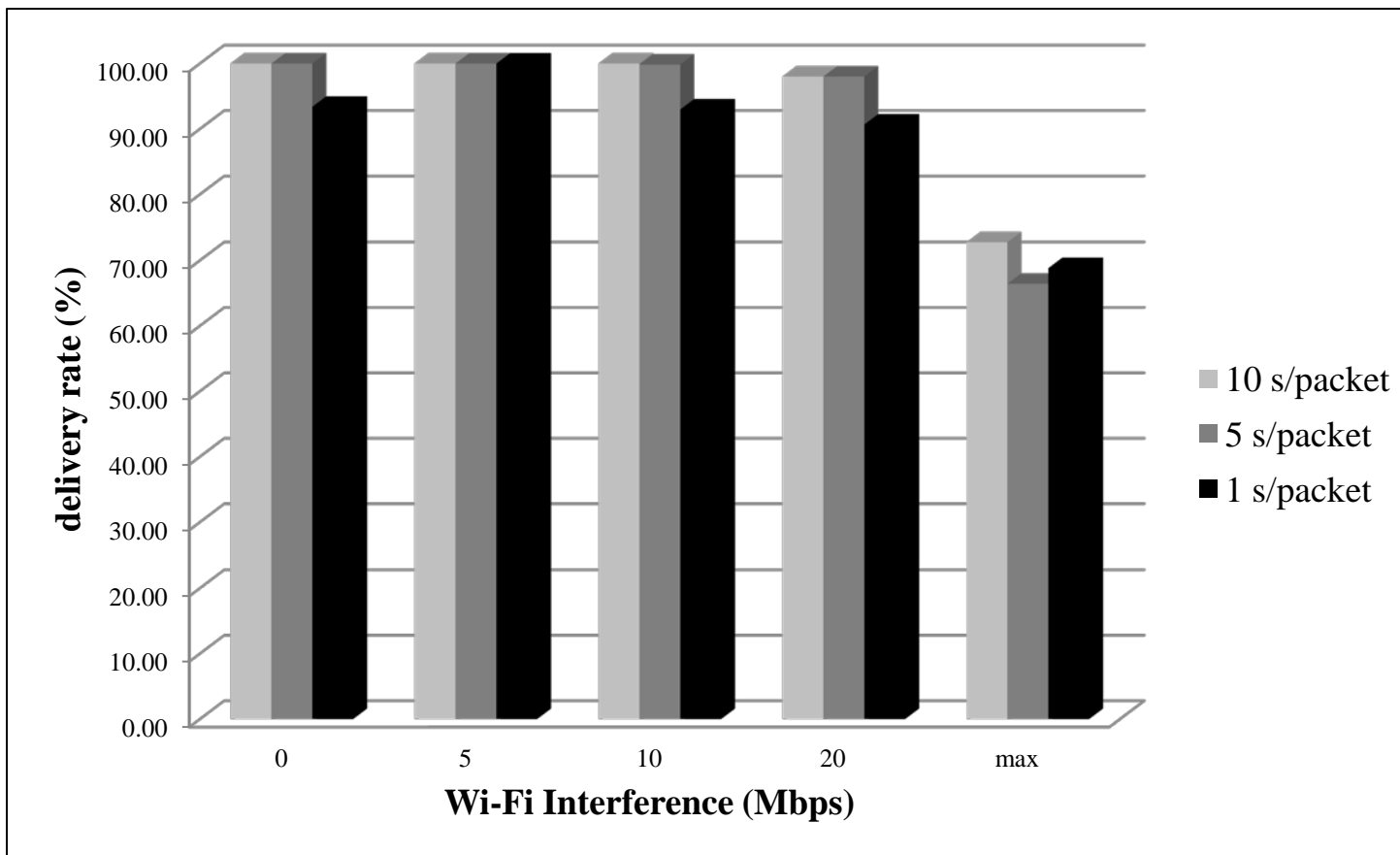


legend:

- GW – WSN gateway
- N1-N5 – WSN nodes
- WFR – Wi-Fi router
- WFC – Wi-Fi client

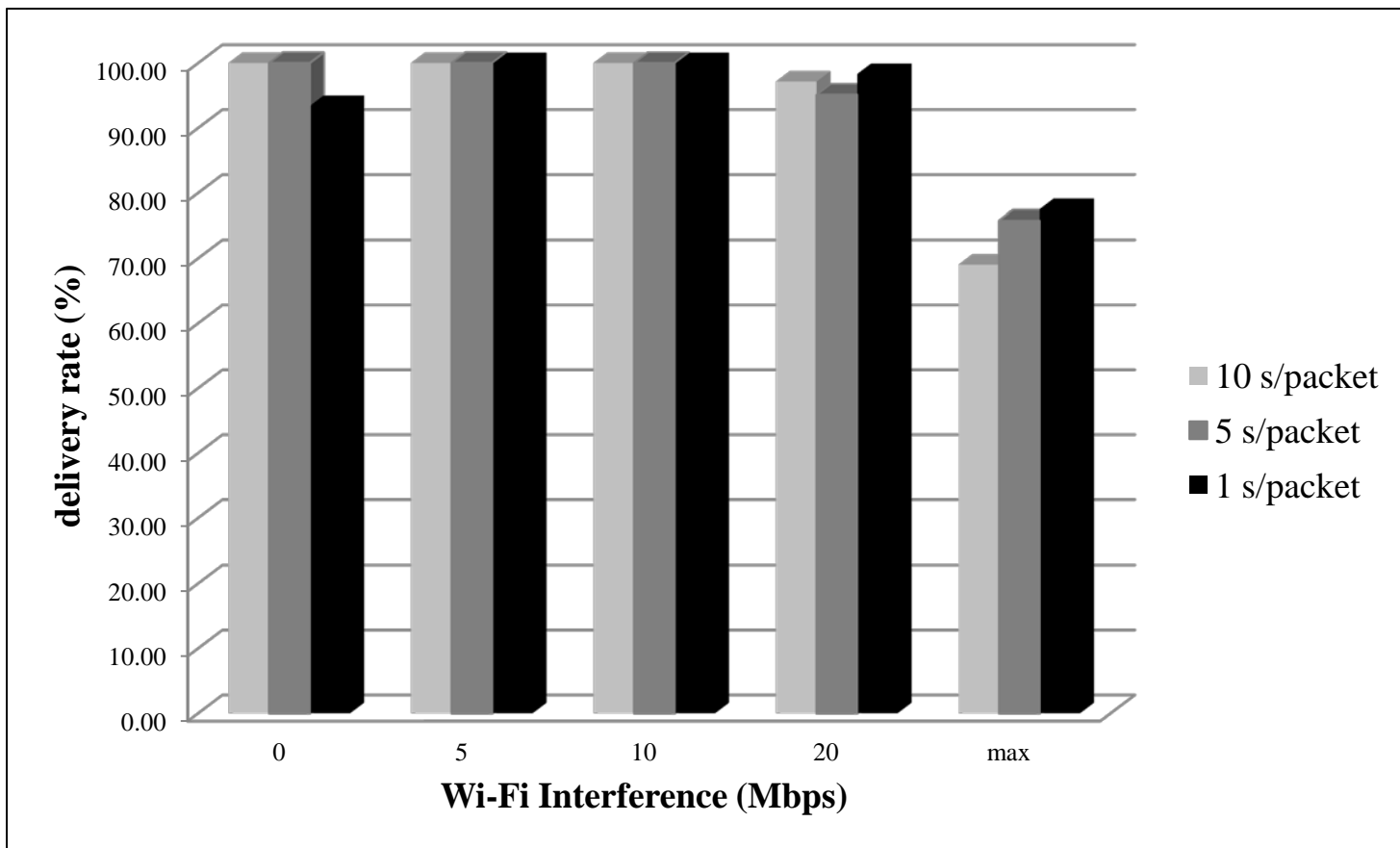


ZigBee – Direct Interference



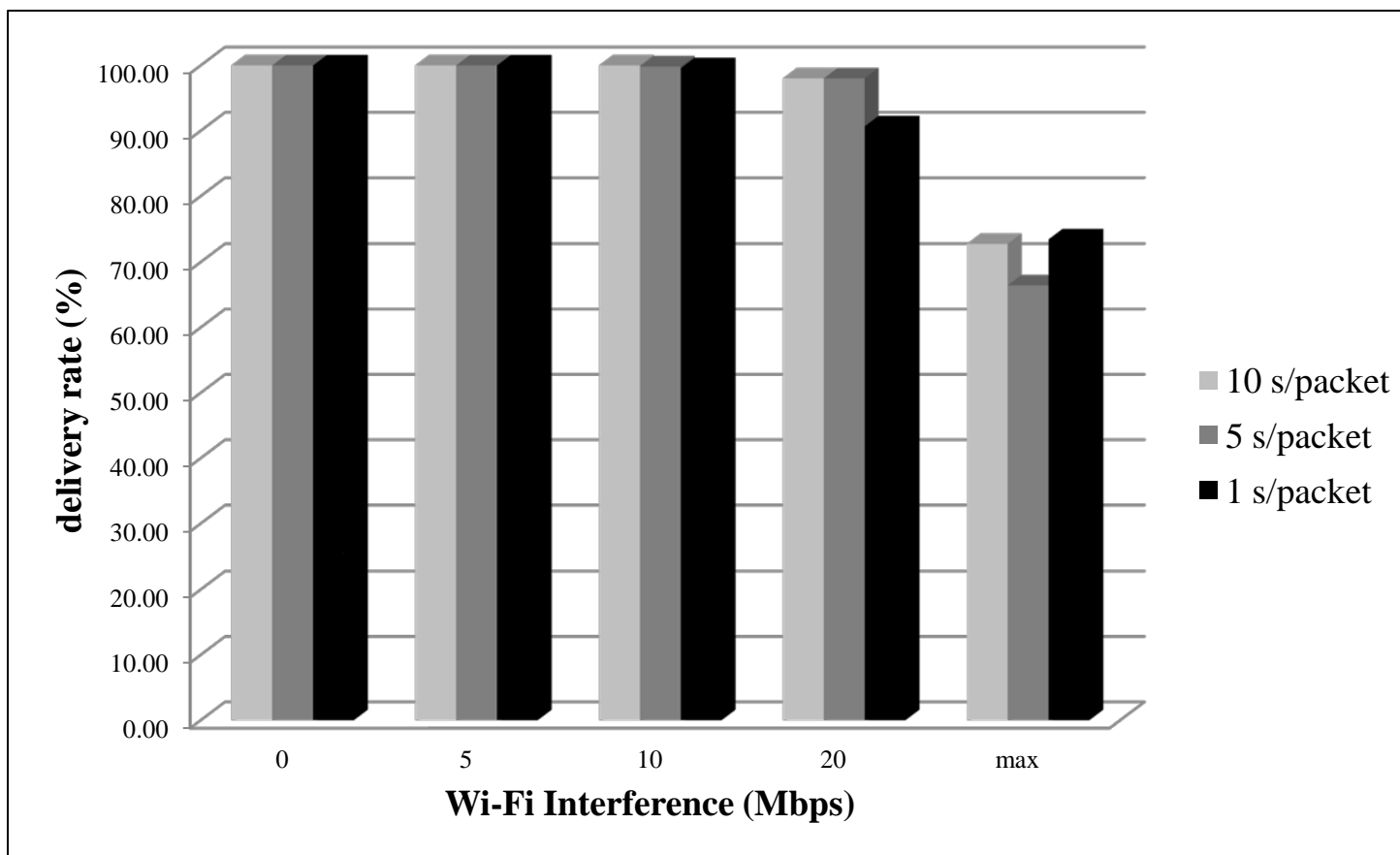


ZigBee – Sideband Interference



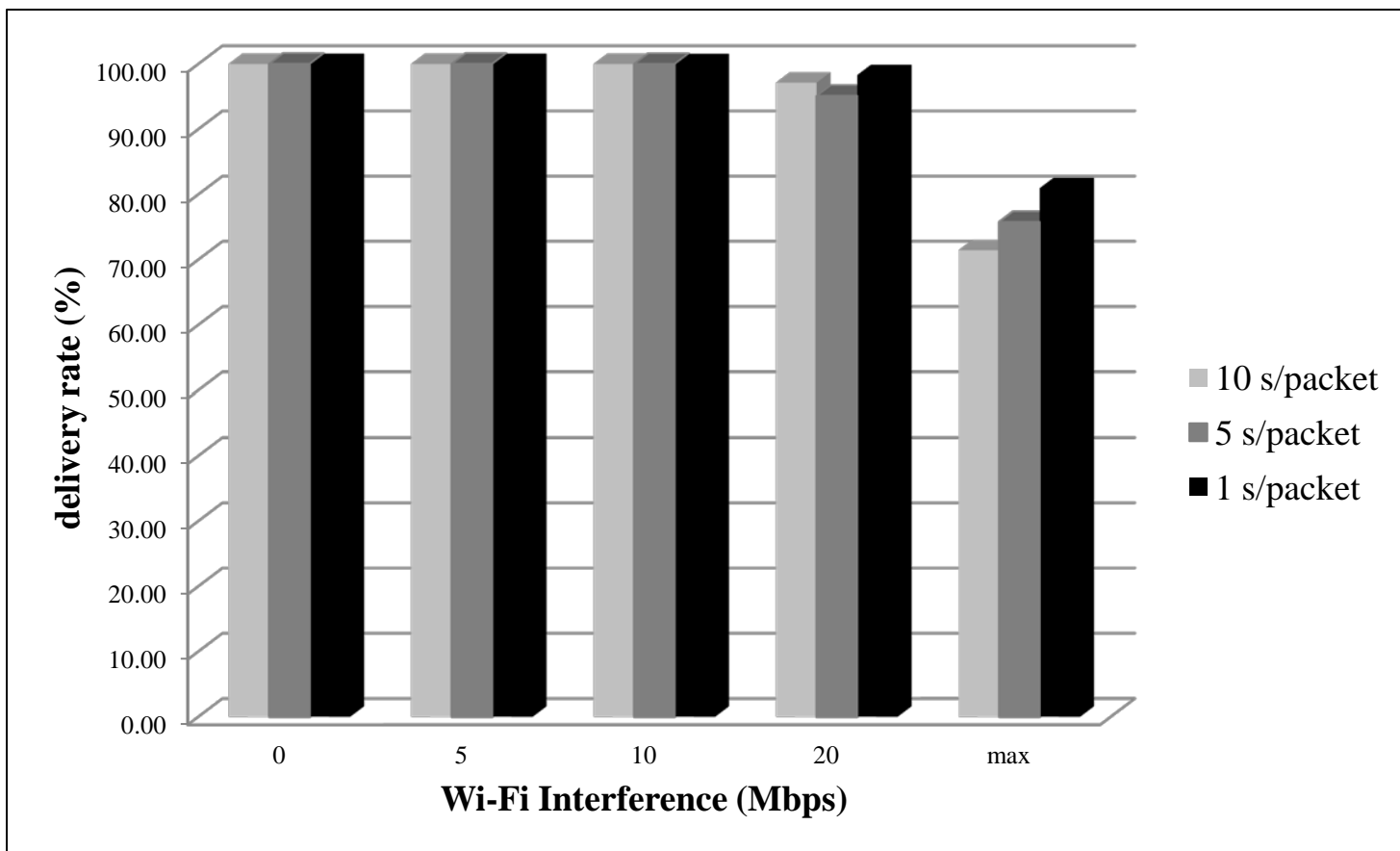


ZigBee – Direct Interference (outliers removed)



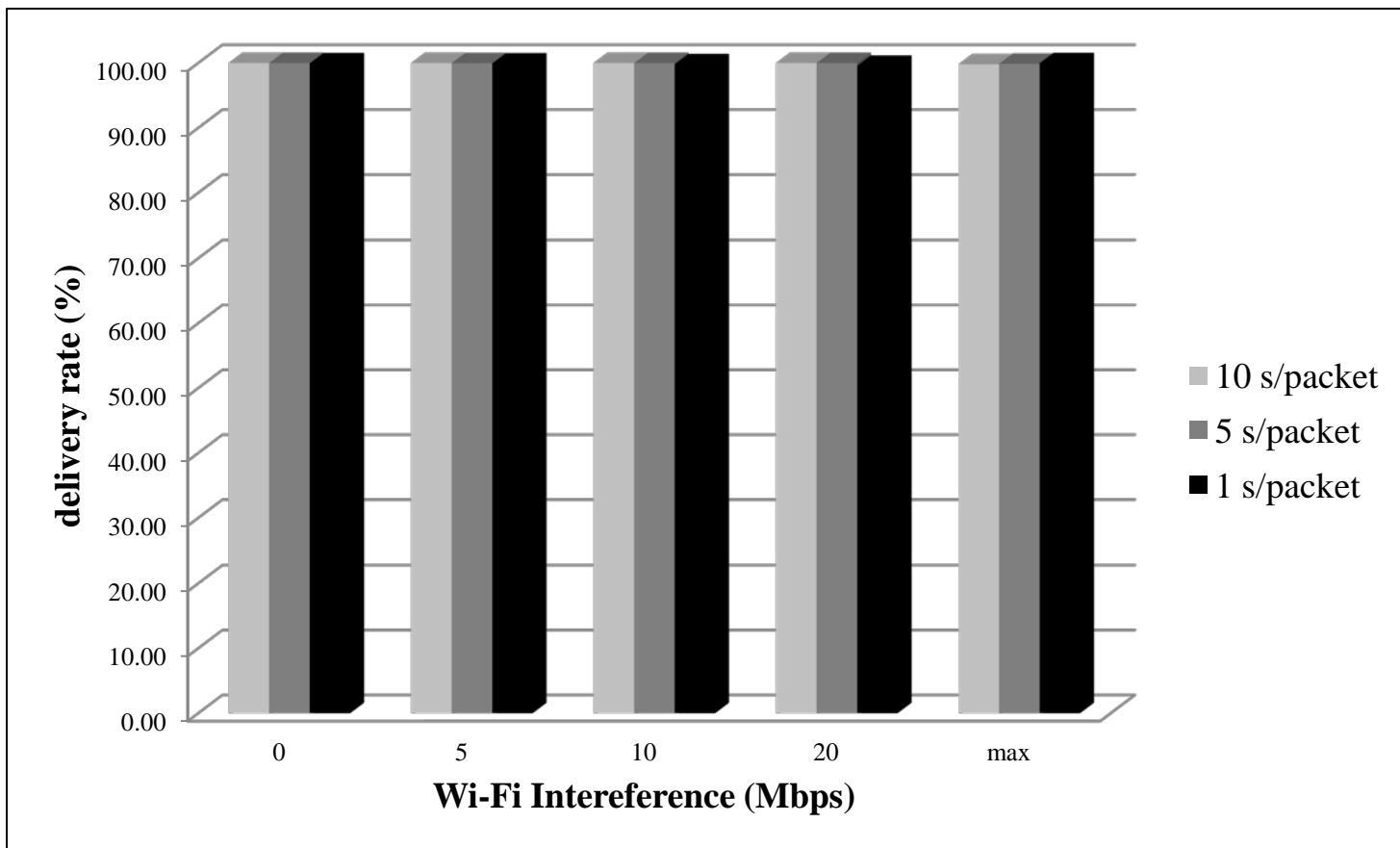


ZigBee – Sideband Interference (outliers removed)





ISA100





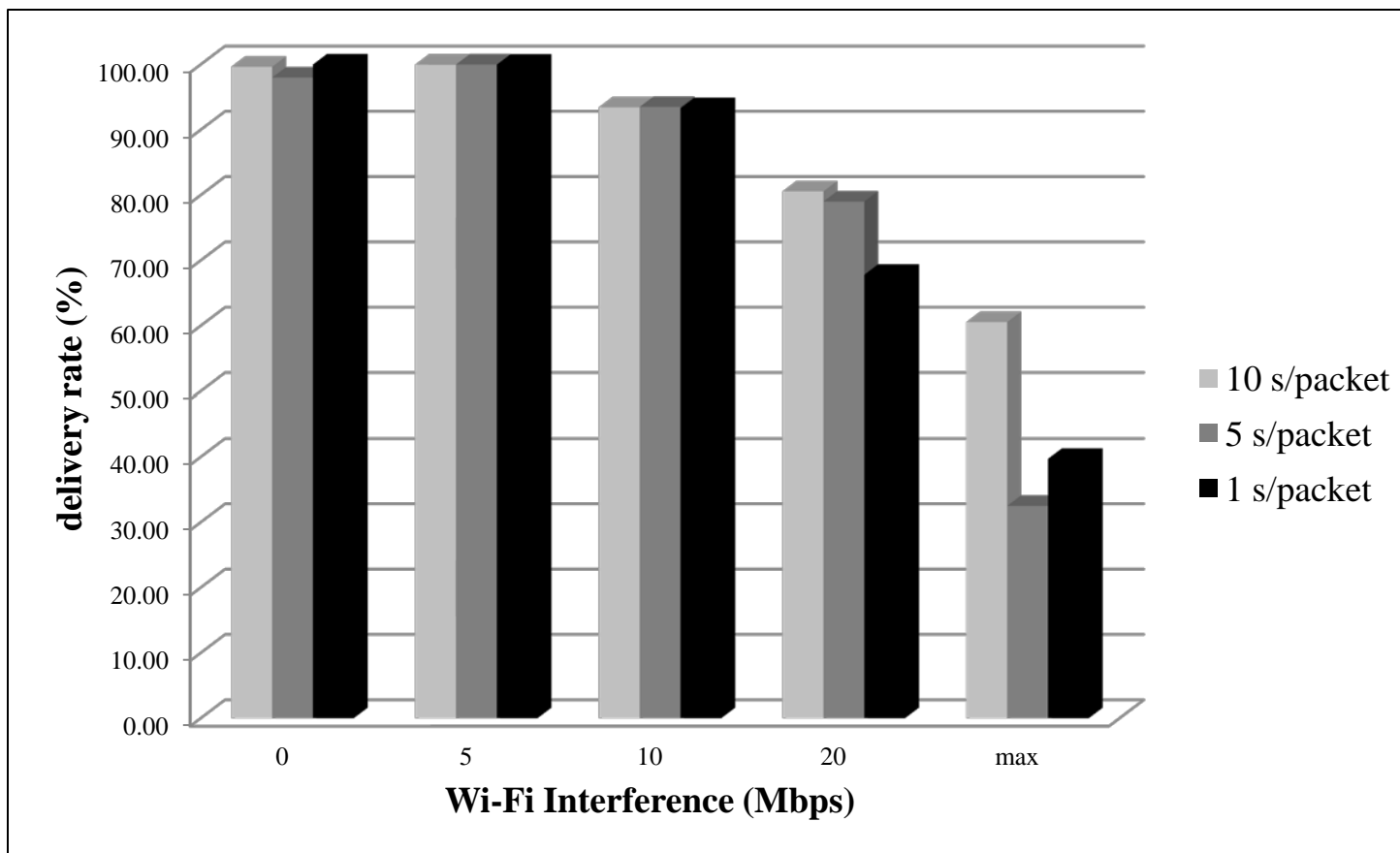
Comparison Summary

	Cost	Network Setup	Throughput	Latency	Interference Tolerance
ZigBee Pro	~\$10/unit	instant-on	higher	variable	low-to-moderate
ISA100.11a	~\$120/unit	centralized optimization	lower	bounded	high

(results appear in *Performance Comparison of Wireless Sensor Network Standard Protocols in an Aerospace Environment: ISA100.11a and ZigBee Pro*, R. Wagner and R. Barton, 2012 IEEE Aerospace Conference)

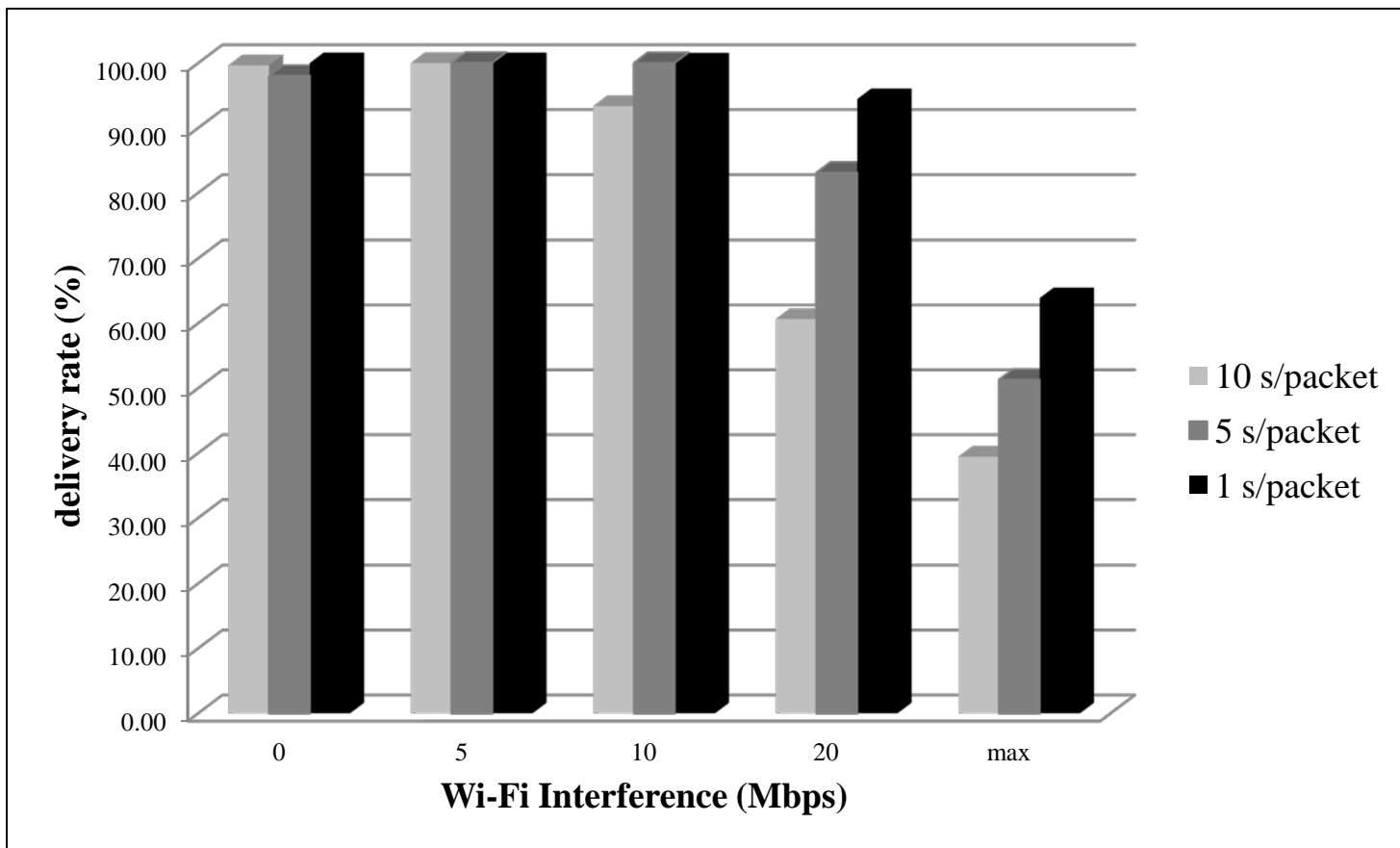


ZigBee – Direct Interference (-3 dBm)





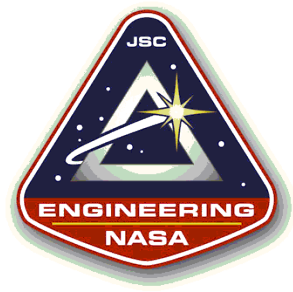
ZigBee – Sideband Interference (-3 dBm)





Conclusions

- **Completed first head-to-head comparison of ZigBee Pro, ISA100.11a presented in the literature**
- **Found that both ZigBee and ISA100.11a have their places**
 - ZigBee: inexpensive, fast network formation, better throughput, good at lower interference levels
 - ISA100.11a: better latency guarantees, more robust at higher interference levels
- **Uncovered occasional ZigBee Pro node disconnections**
 - sometimes intermittent, sometimes permanent
 - ~ 1% of time at +3 dBm output power
 - ~15% of time at -3 dBm output power
 - correlated most strongly with high interference, but happened on occasion at lower interference levels



Forward Work

- **Further characterize ISA100.11a performance:**
 - performance with two or more 802.11 interferers?
 - maximum achievable throughput in closed environment?
- **Further characterize ZigBee Pro performance:**
 - maximum achievable throughput in closed environment?
 - what causes orphaning?
- **Compare ZigBee multi-hop routing approach (AODV) with ISA100 (graph)**
- **Explore effects of 802.11n interference**



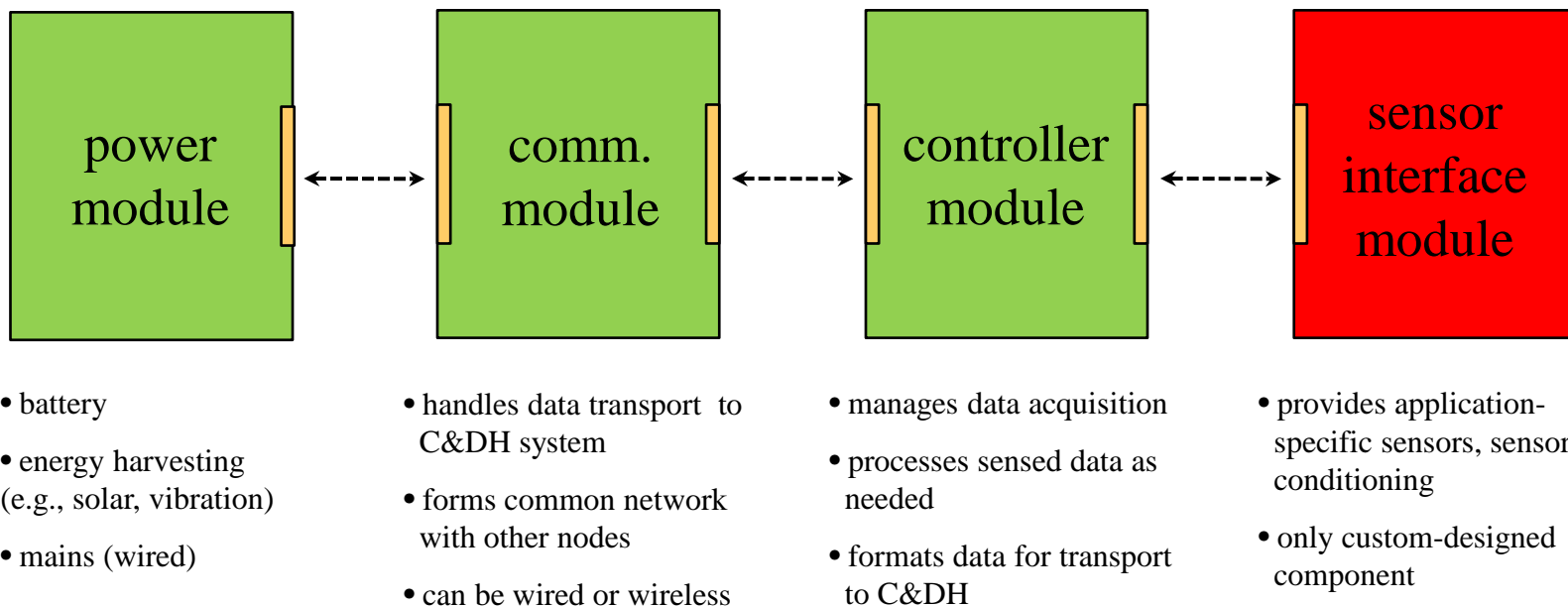
Avionic Systems Division

NASA Johnson Space Center, Houston, Texas

Update on JSC Modular Wireless Instrumentation (“SSIART-NASA”)



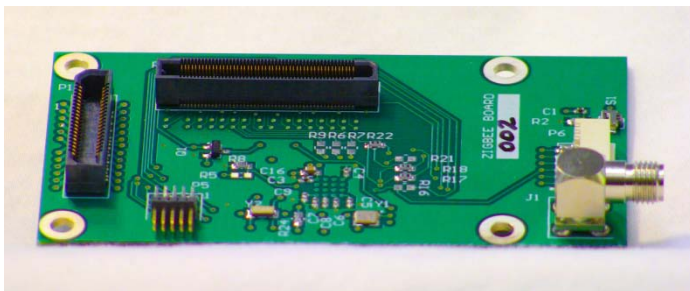
JSC Modular Instrumentation (MI) Architecture



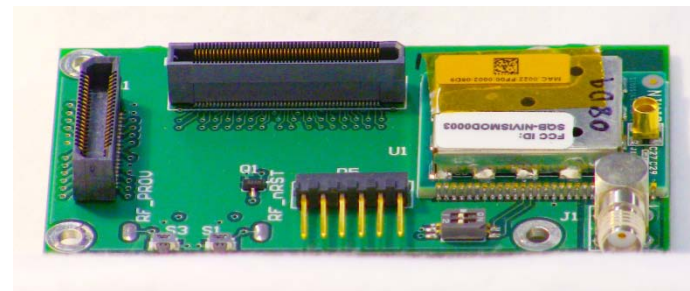


Avionic Systems Division
NASA Johnson Space Center, Houston, Texas

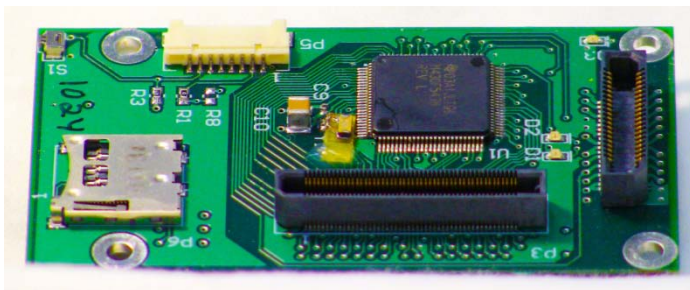
JSC MI Components



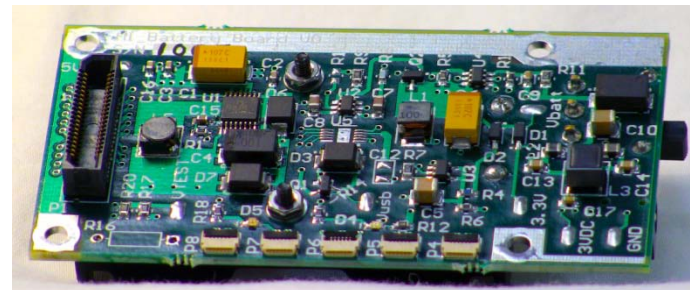
ZigBee Pro radio
(TI CC2530 ZNP)



ISA100.11a radio
(Nivis VN210)



processor
(TI MSP430-F5438,
MSP430F5438a)

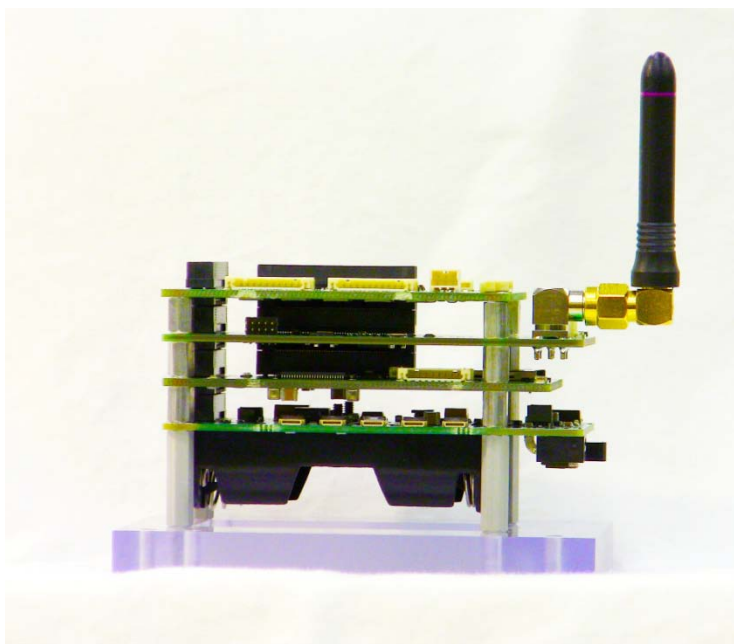


power
(9V wall, AA battery x2)



Avionic Systems Division
NASA Johnson Space Center, Houston, Texas

Modular Instrumentation Stack



side view
(with sensor package)



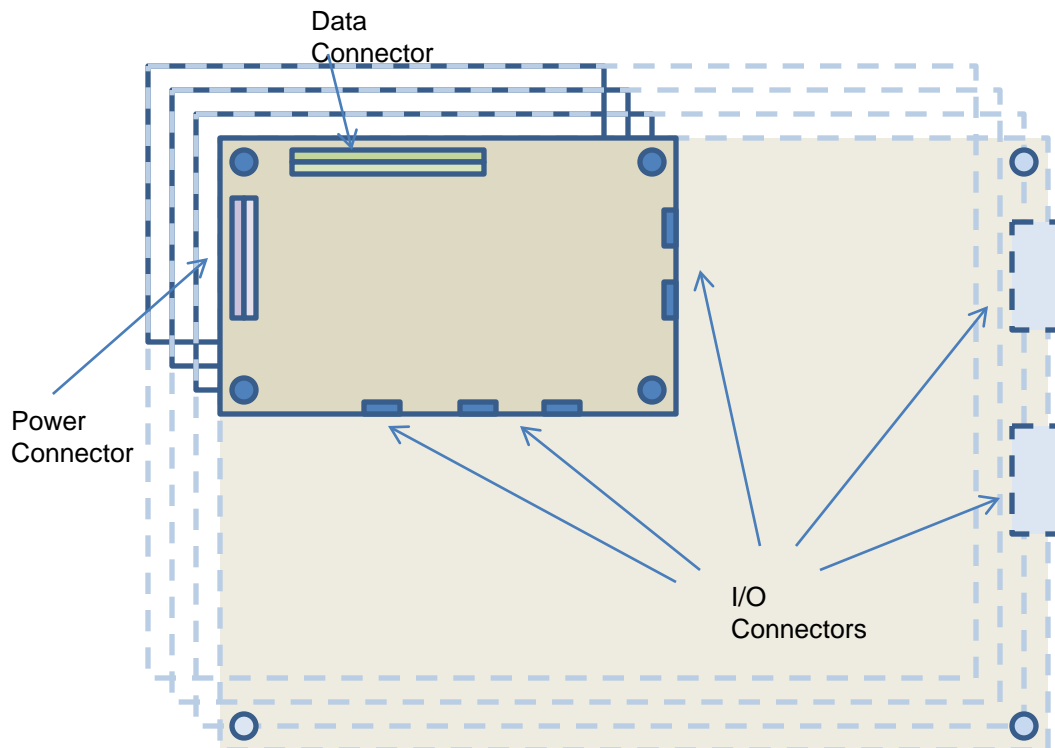
scale view
(with sensor package)



Modular Instrumentation Mechanical Interface

Interface Specification:

- board dimension user-defined
- mounting hole locations pre-defined
- data connector location, pin assignments defined
- power connector location, pin assignments defined
- I/O connector types, locations user-defined

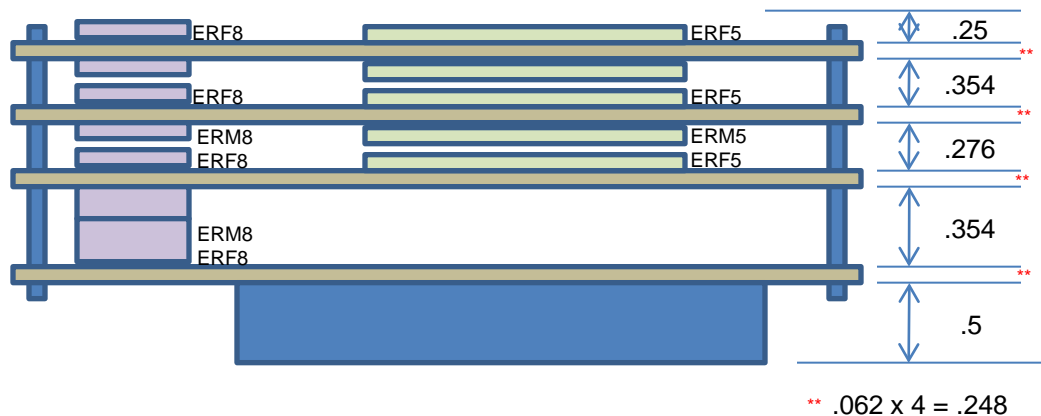




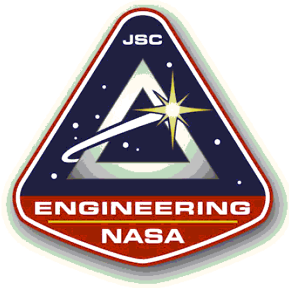
Modular Instrumentation Mechanical Interface

Board Clearance:

- Power, Data bus connector dimensions define board clearances
- mounting hole locations pre-defined
- data connector location, pin assignments defined
- power connector location, pin assignments defined
- I/O connector types, locations user-defined



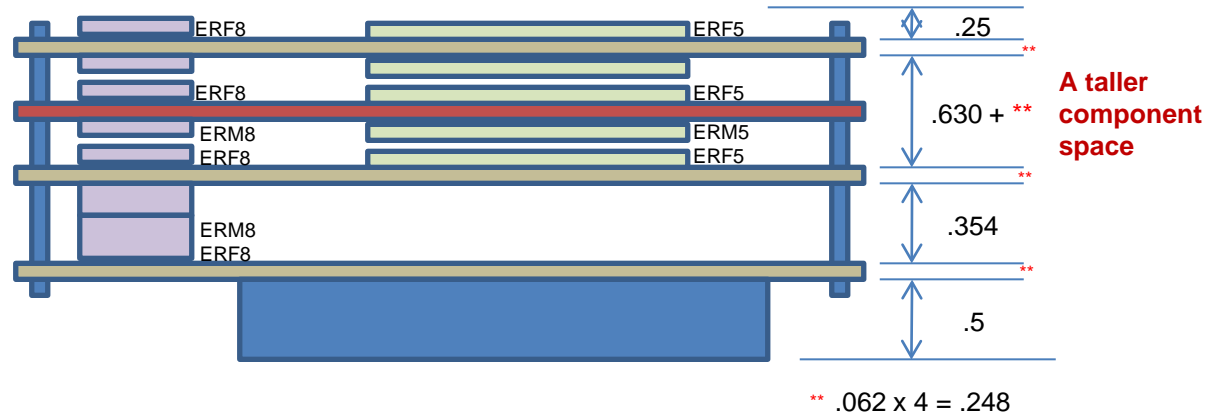
Expected Total Height = 1.982 in



Modular Instrumentation Mechanical Interface

Oversized Components:

- L-shaped adaptor can provide greater inter-board clearance



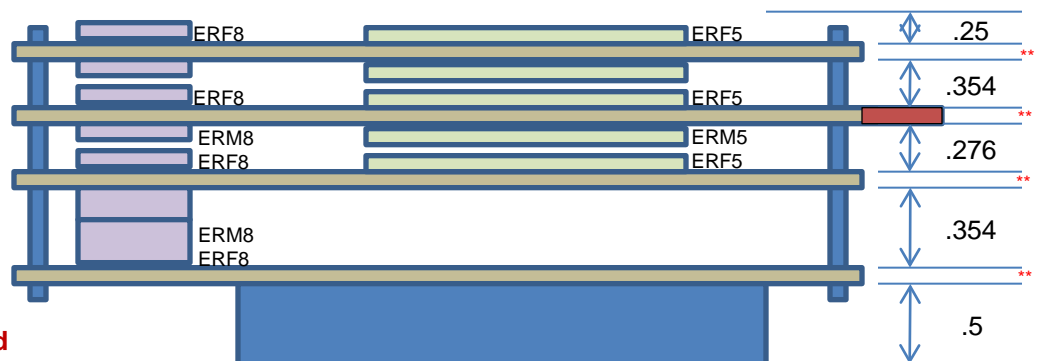
Expected Total Height = 1.982 in



Modular Instrumentation Mechanical Interface

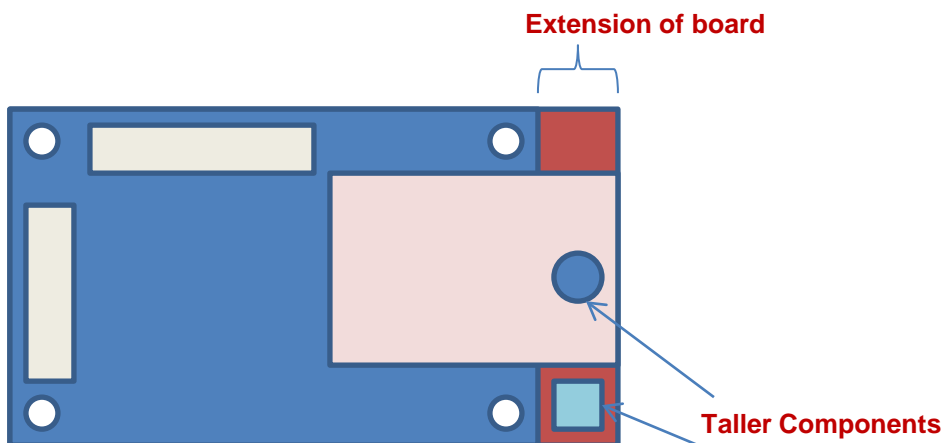
Oversized Components:

- Extending boards past nominal footprint can provide unconstrained vertical component space



** $.062 \times 4 = .248$

Expected Total Height = 1.982 in





Avionic Systems Division
NASA Johnson Space Center, Houston, Texas

Update on JSC High-Speed Wireless Instrumentation Needs



Deep Space Habitat (DHS) Project

- **Project description**
 - Define and mature a DHS element that will enable human exploration beyond earth orbit (BEO)
 - Focus and Infuse habitat-related exploration technologies
 - Transition habitat-related products into the Habitat Demonstration Unit (HDU) prototype for integrated systems and mission testing
- **Current wireless capability**
 - ISA100.11a low-power, low data-rate WSN
 - Currently used for environmental monitoring and control
 - Primarily temperature and pressure data
 - EPCGlobal, Gen 1, Class 2 RFID
 - Inventory, tool, and sample tracking
- **Projected high data-rate wireless applications**
 - High frequency phenomena
 - Impact/leak detection and localization
 - Vibration/load monitoring during launch and docking
 - Structural health monitoring (shape and vibration)
 - Power transient monitoring
 - Non-destructive evaluation (NDE)
 - Real-time audio and HD video streams
 - Medical monitoring (very high priority)
 - Real-time telemedicine
 - Mobile crewmember monitoring
 - Increased security requirements to ensure privacy and data integrity



Project Morpheus

- **Project description**
 - Morpheus is a vertical test bed vehicle demonstrating new green propellant propulsion systems and autonomous landing and hazard detection technology
- **Current wireless capability**
 - 900 MHz, low data-rate command and telemetry ground link
 - 2 redundant UHF links for abort commanding
- **Projected high data-rate wireless applications**
 - Monitor high frequency phenomena on-board
 - Vibration/load monitoring during flight
 - Power transient monitoring in control systems
 - Real-time HD video streams
 - Stream full-bandwidth telemetry during flight
 - Enables real-time transient and diagnostic monitoring
 - Archive data to prevent total loss of data on vehicle malfunction
 - Wireless sensors for Autonomous Landing and Hazard Avoidance Technology (ALHAT)



Avionic Systems Division

NASA Johnson Space Center, Houston, Texas

Backup



ZigBee – Direct Interference

Interference Bandwidth:	Seconds Between packets	Test 1:	Test 2:	Test 3:	Average:	Std.Dev. of Tests:	Std. Dev. of Nodes:
0	1	100.00	100.00	80.17	93.39	11.45	25.60
5	1	100.00	100.00	100.00	100.00	0.00	0.00
10	1	80.13	99.82	99.00	92.99	11.14	25.54
20	1	83.39	94.31	94.35	90.68	6.32	5.88
max	1	73.50	56.65	76.32	68.82	10.64	18.99
0	5	100.00	100.00	100.00	100.00	0.00	0.00
5	5	100.00	100.00	100.00	100.00	0.00	0.00
10	5	99.81	99.94	99.78	99.84	0.09	0.34
20	5	97.92	99.39	96.75	98.02	1.32	2.09
max	5	58.50	69.56	71.25	66.44	6.92	12.83
0	10	100.00	100.00	100.00	100.00	0.00	0.00
5	10	100.00	100.00	100.00	100.00	0.00	0.00
10	10	100.00	100.00	100.00	100.00	0.00	0.00
20	10	97.83	98.89	97.33	98.02	0.79	1.95
max	10	71.22	74.89	72.22	72.78	1.90	4.70



ZigBee – Sideband Interference

Interference Bandwidth:	Seconds Between packets	Test 1:	Test 2:	Test 3:	Average:	Std.Dev. of Tests:	Std. Dev. of Nodes:
5	1	100.00	100.00	100.00	100.00	0.00	0.00
10	1	100.00	99.98	99.98	99.99	0.01	0.02
20	1	99.26	98.74	96.93	98.31	1.23	1.88
max	1	81.32	69.45	81.78	77.52	6.99	14.05
5	5	100.00	100.00	100.00	100.00	0.00	0.00
10	5	100.00	100.00	99.97	99.99	0.02	0.04
20	5	90.44	96.28	98.58	95.10	4.19	4.42
max	5	74.50	77.39	75.39	75.76	1.48	4.13
5	10	100.00	100.00	100.00	100.00	0.00	0.00
10	10	100.00	100.00	100.00	100.00	0.00	0.00
20	10	97.06	95.83	98.56	97.15	1.36	2.36
max	10	71.39	66.11	69.56	69.02	2.68	10.75



Avionic Systems Division

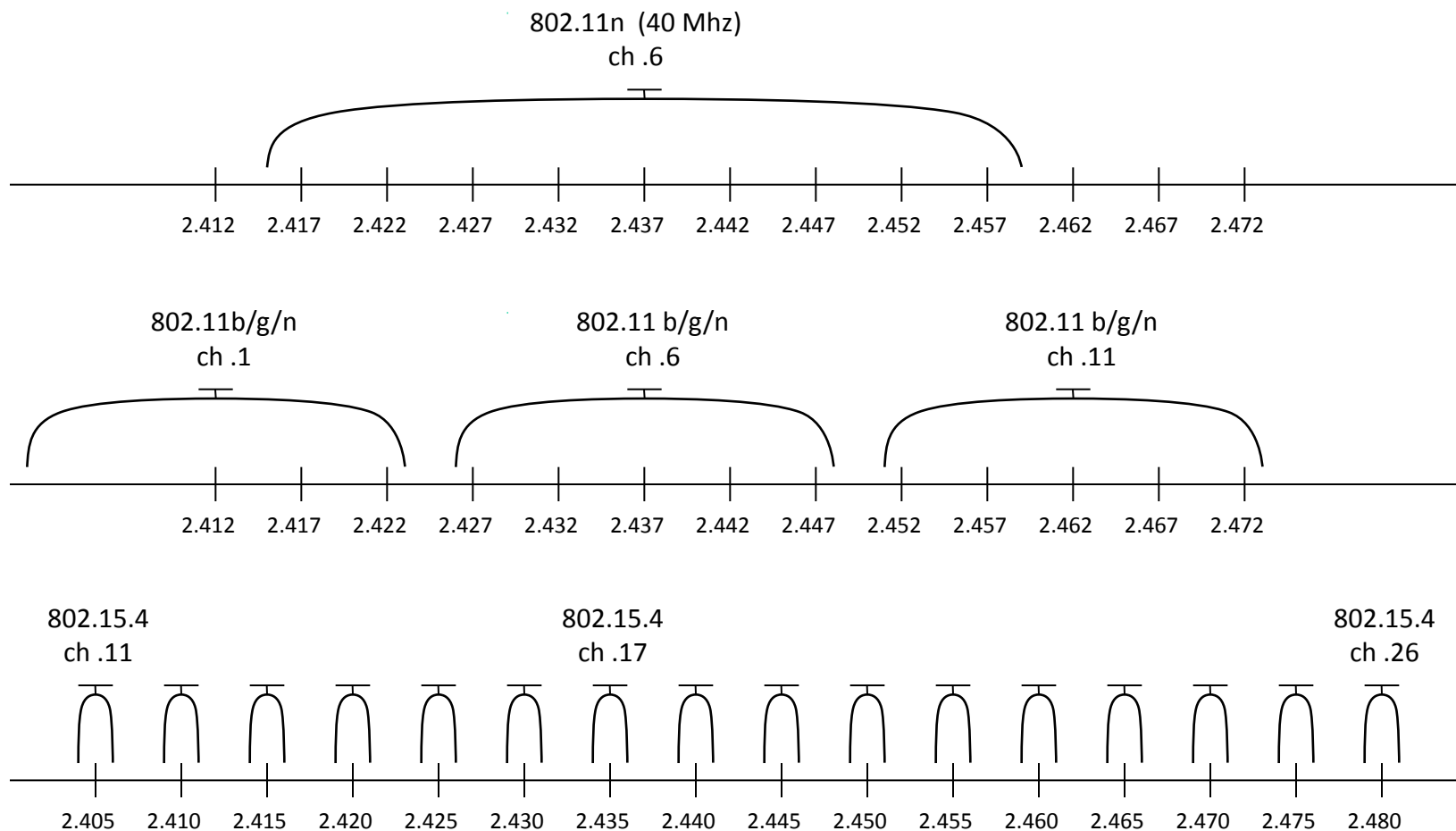
NASA Johnson Space Center, Houston, Texas

ISA100

Interference Bandwidth:	Seconds Between packets	Test 1:	Test 2:	Test 3:	Average:	Std.Dev. of Tests:
5	1	99.93	99.95	99.96	99.95	0.015
10	1	99.94	99.92	99.94	99.93	0.012
20	1	99.72	99.96	99.74	99.81	0.133
max	1	99.43	99.92	99.37	99.57	0.302
5	5	99.97	99.97	99.98	99.97	0.006
10	5	100	100	100	100.00	0.000
20	5	99.97	99.94	100	99.97	0.030
max	5	99.97	100	100	99.99	0.017
5	10	100	100	100	100.00	0.000
10	10	99.88	99.83	99.94	99.88	0.055
20	10	100	100	100	100.00	0.000
max	10	100	100	100	100.00	0.000



802.15.4, 802.11b/g/n Co-existence





Avionic Systems Division
NASA Johnson Space Center, Houston, Texas

WSNs in the Wild

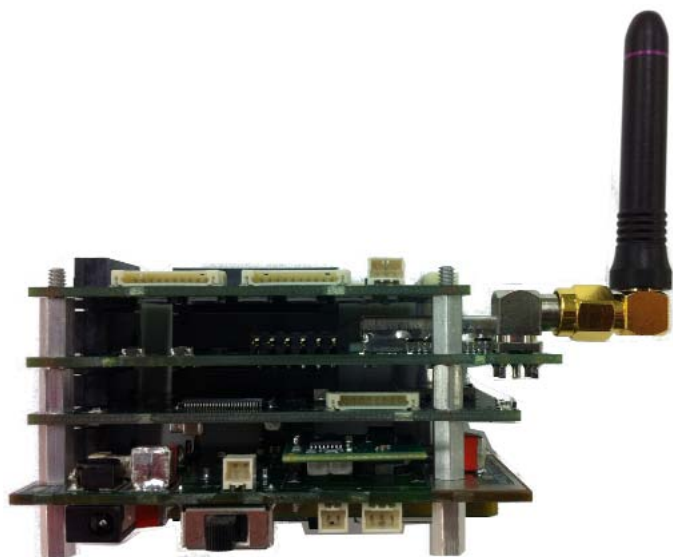


ISA100.11a
node

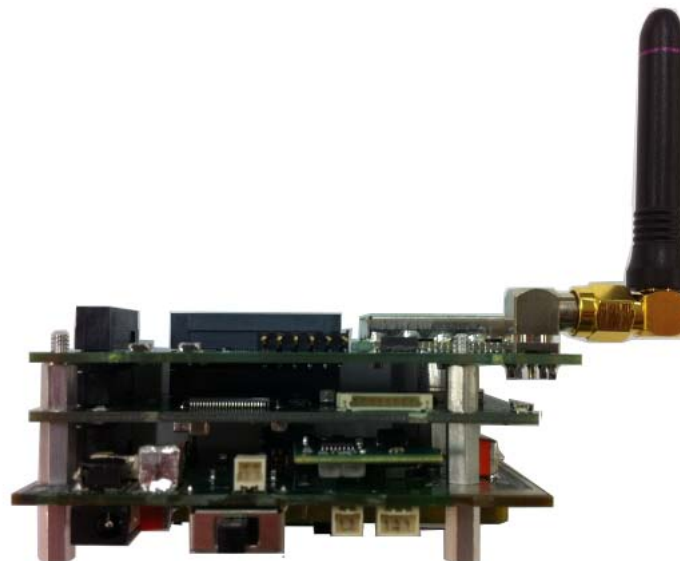


Avionic Systems Division
NASA Johnson Space Center, Houston, Texas

Modular Instrumentation Stack



4 board stack
(inc. sensors)



3 board stack